Deformation Measurements at the Vehicle Tunnel Overpass using a Hydrostatic Level System

Advanced Photon Source

H. Friedsam, J. Penicka, J. Error - April 1996

1. Introduction

Long-term storage ring and experiment hall floor settlements are being monitored on a regular bases in six-month intervals utilizing common geometric leveling techniques . One area of concern requiring special attention in terms of settlements is the vehicle tunnel that undercuts the experiment hall and storage ring at the south side of the APS. Five user beamlines crossing over the vehicle tunnel could be affected by deformations in this area [1].

Assuming the most severe temperature fluctuations would occur during the winter time, a monitoring system was installed at the beginning of 1996. The length of the experiment was dictated by the installation schedule of the user enclosures at the overpass.

2. Purpose of the Experiment

From January 4, 1996 to March 25, 1996 a hydrostatic level system recorded deformation data at the vehicle tunnel overpass. Four sensors were installed along the tunnel centerline on the experiment hall floor. Two additional sensors were mounted further away from the tunnel overpass to provide a stable reference. All six sensors were interconnected by water and air tubes providing a closed-loop system. The layout of the sensors is shown in Figure 1.

Due to the operation schedule of the accelerator it was not possible to extend the experiment into the storage ring tunnel without compromising the shielding requirements.

During the same time period fluctuations of the outside air temperature were recorded at the ANL meteorological tower in close proximity to the APS. This provided the means to correlate air temperature with measured deformations.

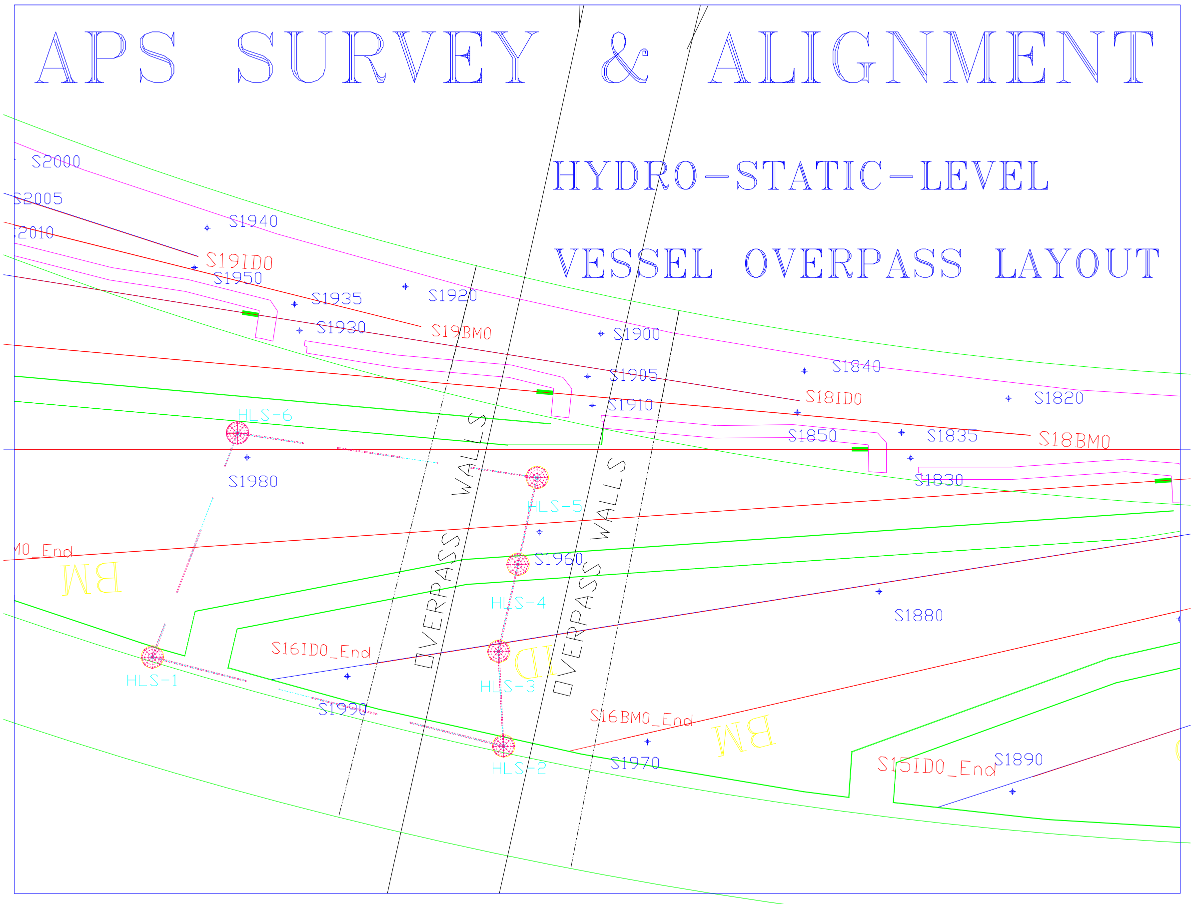

Fig. 1 Hydrostatic level layout

3. Measurement Principle

Hydrostatic level systems for the measurement of elevation differences have been utilized for centuries. The principal was even known to our Greek ancestors. The concept remained the same over time and is based on the equilibrium of the pressure of liquid in communicating vessels. The part that has changed in a modern hydrostatic level system is the means by which the height of the water column in a vessel is determined. This development has improved the achievable accuracy of the instrument and is, in the case of the *Fogal Nanotech* system, ±5µm for the determination of an elevation difference between two vessels [2].

Figure 2 shows a schematic of the principal. Assuming that the liquid used has a homogeneous density ρ and the gravitational force g and air pressure P are the same at both vessels, one can deduce the elevation difference between the two vessels merely by subtracting the measured height of the liquid column at each vessel from the other [3].

It can be assumed that the gravitational forces are almost identical at the two vessel locations if the vessels are located in a 10 km^2 area.

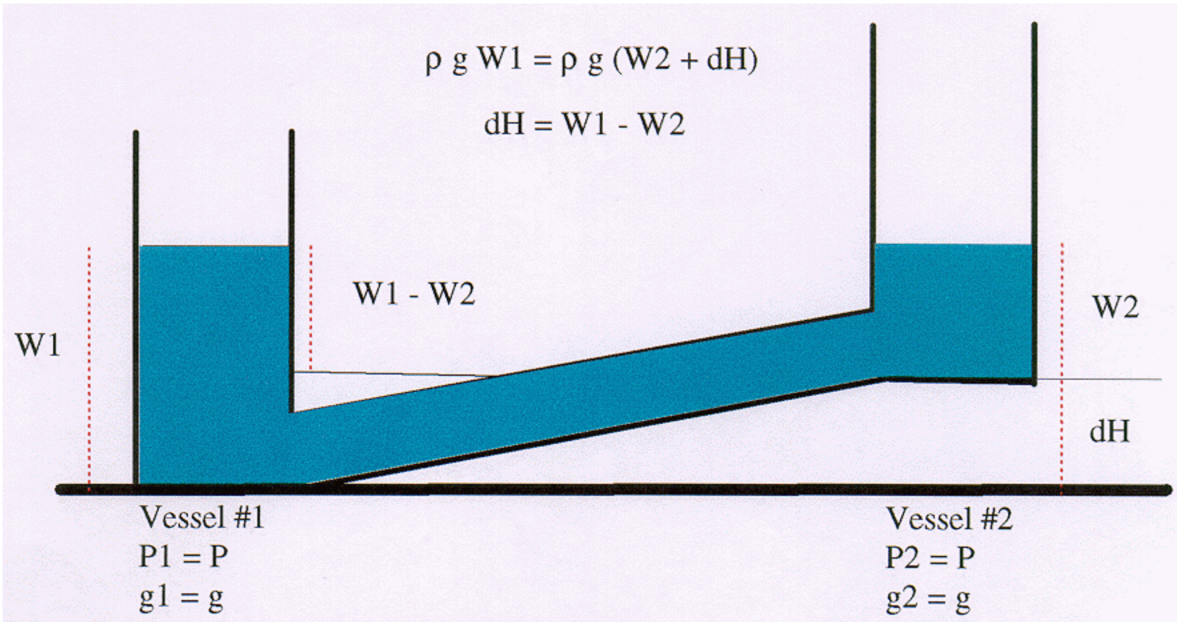

Fig. 2 Principal of a hydrostatic level system

High-precision hydrostatic level systems [4] [5] [6] are usually interconnected by air tubes to ensure that all vessels experience the same air pressure. Only at one vessel is a small opening provided. The pressure from that location is distributed to all other vessels.

In order to minimize the influence of temperature gradients in the liquid tubes that interconnect the vessels, the tubes are laid out in a horizontal plane intersecting all vessels. In addition, the height of the liquid columns in the vessels is only slightly larger than the tube diameter. Usually water is used to represent the reference plane. The density of water, shown in Figure 3, is largest at about 4°C and drops with increasing temperature. Therefore a 1°C temperature differential between two vessels has almost no effect on the elevation difference

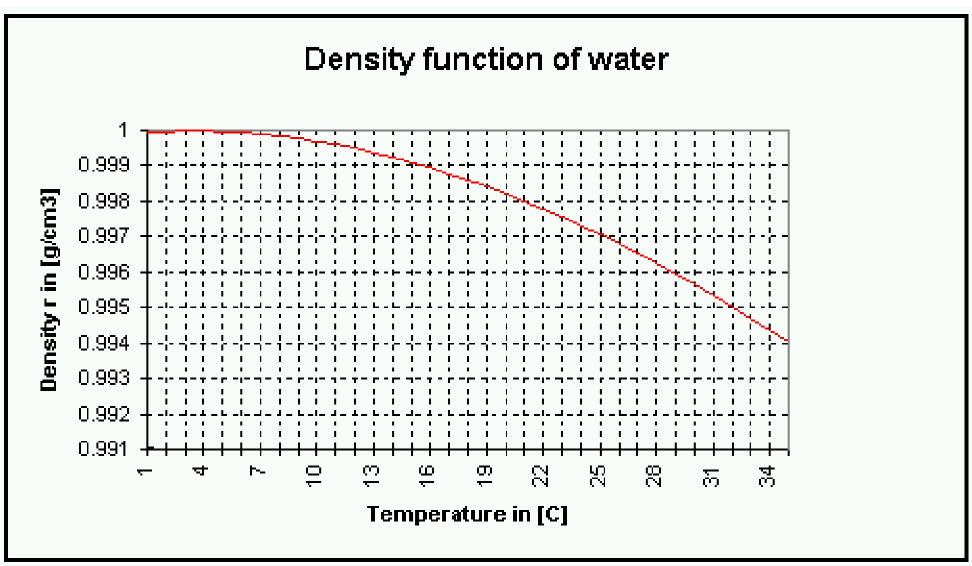

Fig. 3 Density function of water

between these vessels, if the water has a temperature of about 4°C. However, if the water temperature is about 20°C, a 1°C temperature differential would result in a noticeable elevation difference of 0.2mm. Table 1 shows the elevation change due to a 1°C temperature differential for increasing water temperatures [7].

Water Temperature in [°C]	Elevation difference in [mm]
4 - 5	0.00
10 - 11	0.09
20 - 21	0.20
30 - 31	0.30
40 - 41	0.38
50 - 51	0.46

Table 1 Elevation differences versus water temperature changes

The water temperature usually approaches the ambient air temperature which in the case of these deformation measurements is on the order of 20°C. All vessels of the *Fogal Nanotech* HLS have been fitted with temperature sensors, so that temperature fluctuations of the water can be compensated during the measurement process.

4. Data Analysis

For this experiment two of the six sensors have been positioned in an area not undercut by the vehicle tunnel. One of these sensors is considered stable while the second provides some redundancy to test that assumption. The second sensor shows little or no change over the measurement period. Sensor HLS-6 (see Fig. 1) was chosen as the reference for two reasons. First, it was located furthest away from the vehicle tunnel and the outside siding of the experiment hall enclosure. Second, this sensor showed the least amount of fluctuation in water temperature.

All measurements of the other sensors have been reduced to sensor HLS-6. The graphs provided in the next section show elevation differences and water temperature differences with respect to that sensor (labeled C6). This method also eliminates the effect of a virtual elevation change due to evaporation of water over time. Evaporation reduces the water level equally so that, by differencing to the reference sensor, this effect is canceled.

In theory, the sum of the measured water column heights of all vessels should be constant in a closed hydrostatic level system. However, as a result of water evaporation, a monotone decreasing function can be observed. This is shown in Figures 7, 11 and 15 of the next section.

5. Results

The following graphs present the measured elevation and water temperature differences of each sensor with respect to sensor six. A graph is also provided for the recorded outside air temperature and the change of the water level over time due to evaporation. These graphs have been provided for the months of January (Fig. 4 - 7), February (Fig. 8 - 11), and March (Fig. 12 - 15) of 1996.

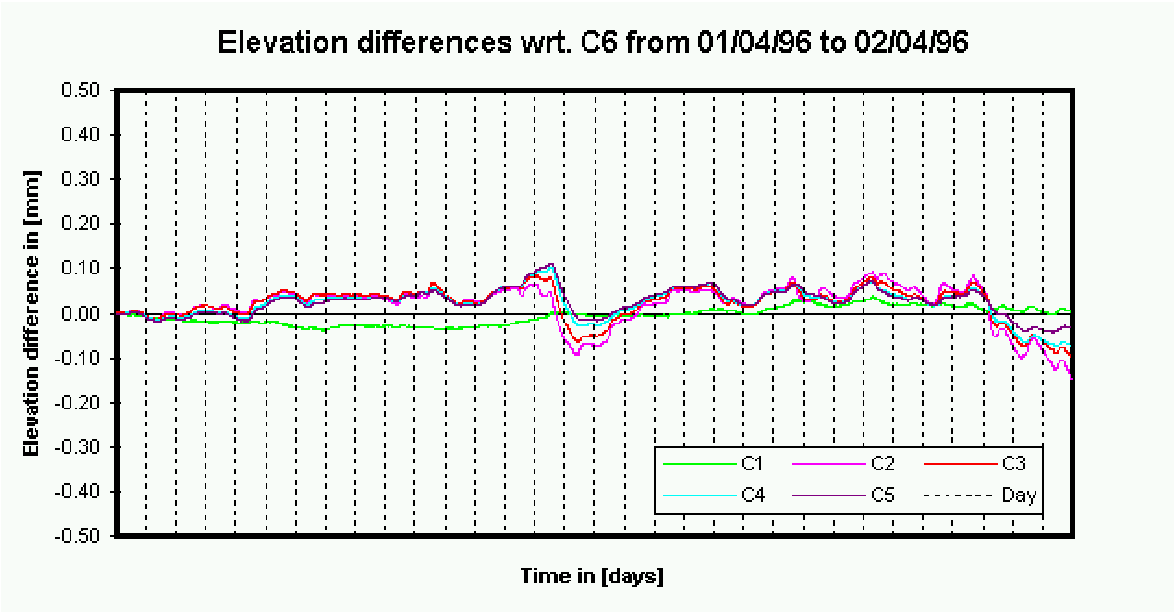

Fig. 4 January elevation differences

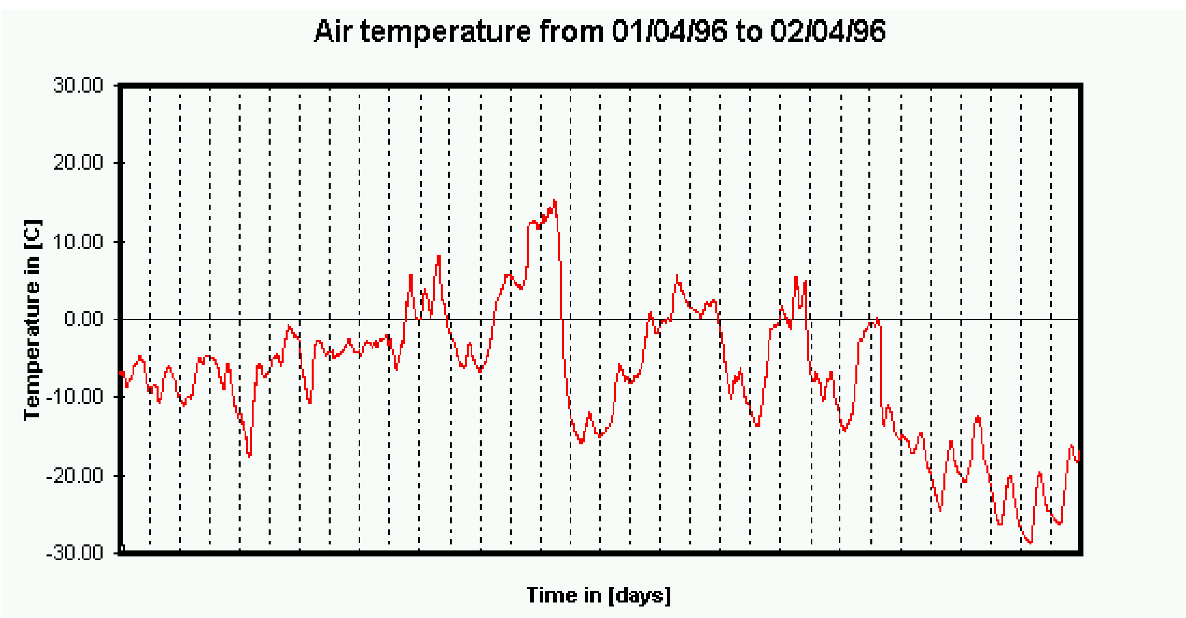

Fig. 5 January air temperature

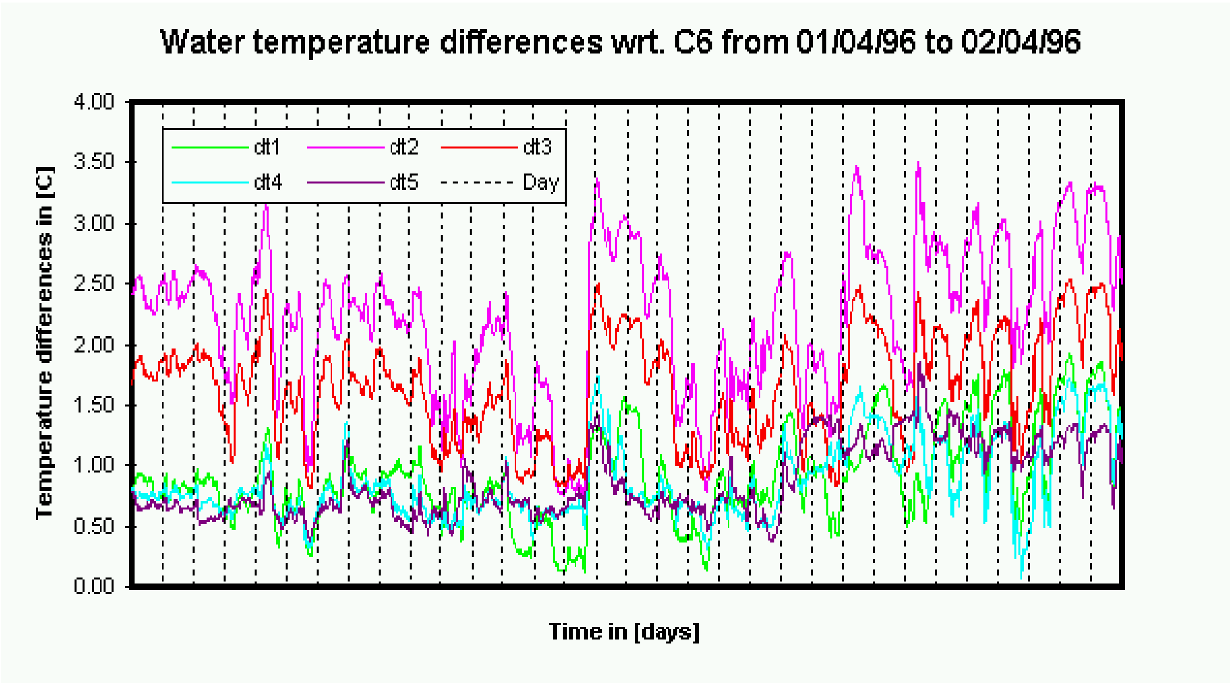

Fig. 6 January water temperature differences

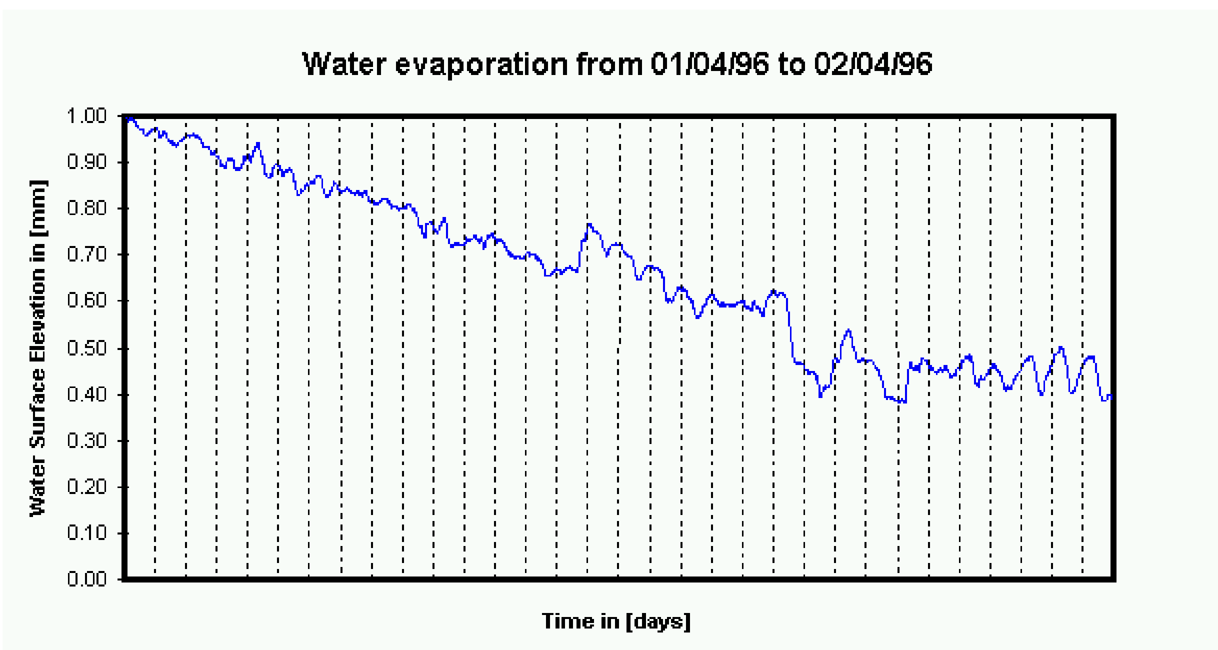

Fig. 7 January water evaporation

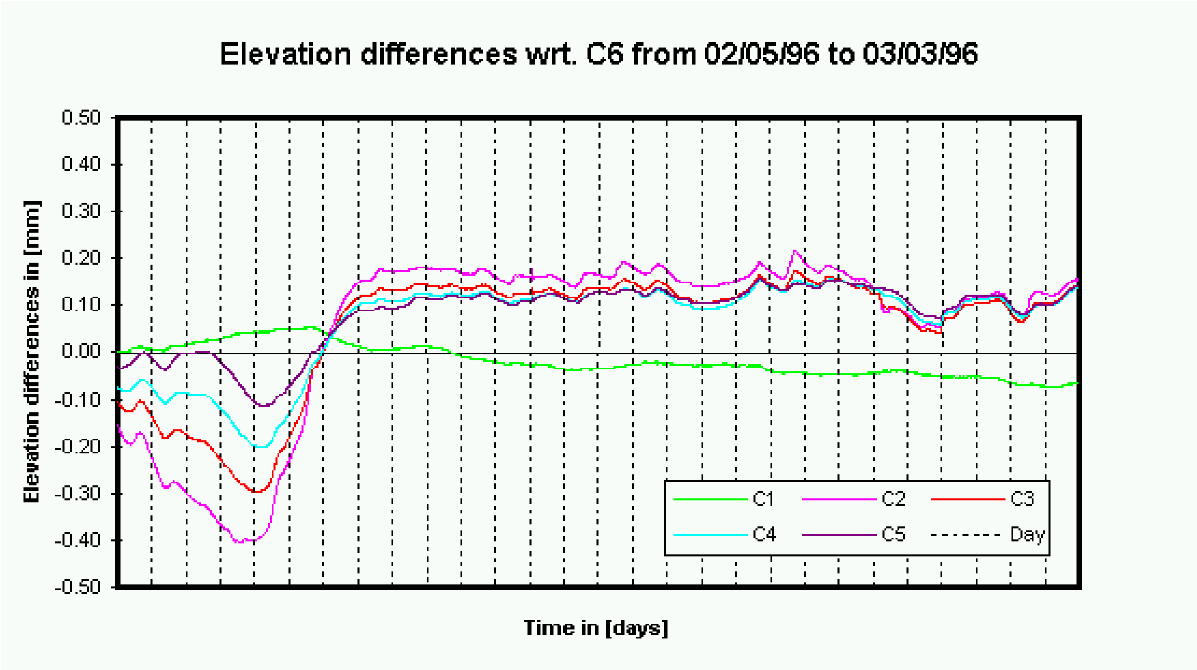

Fig. 8 February elevation differences

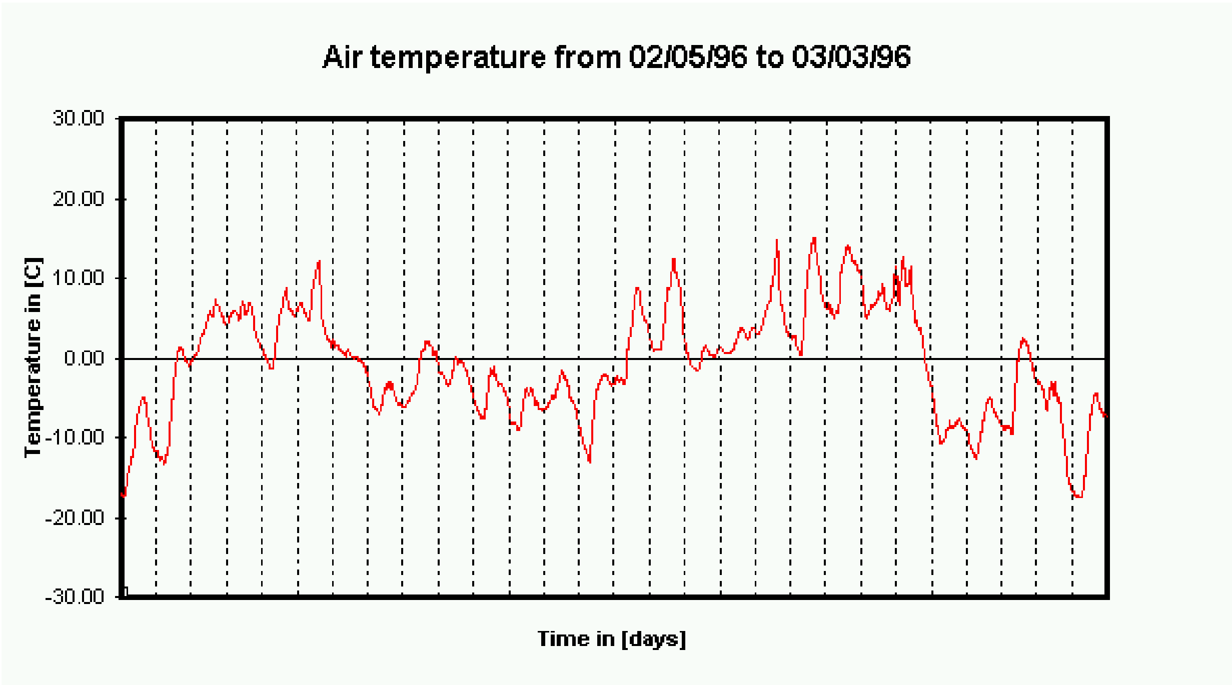

Fig. 9 February air temperature

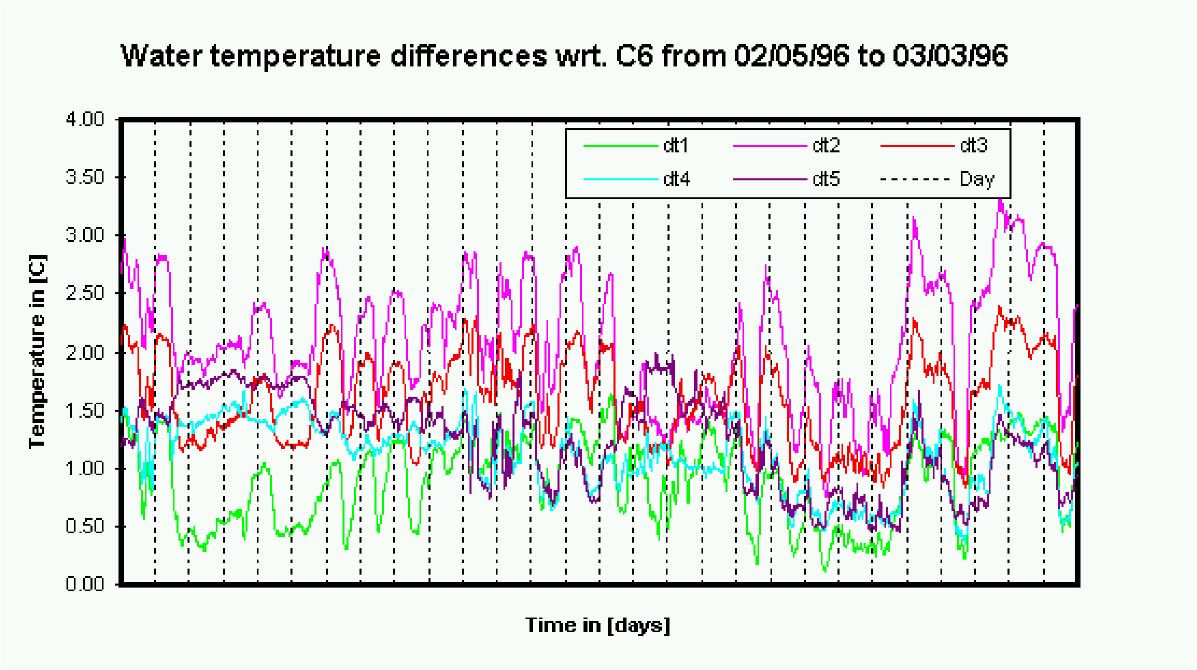

Fig. 10 February water temperature differences

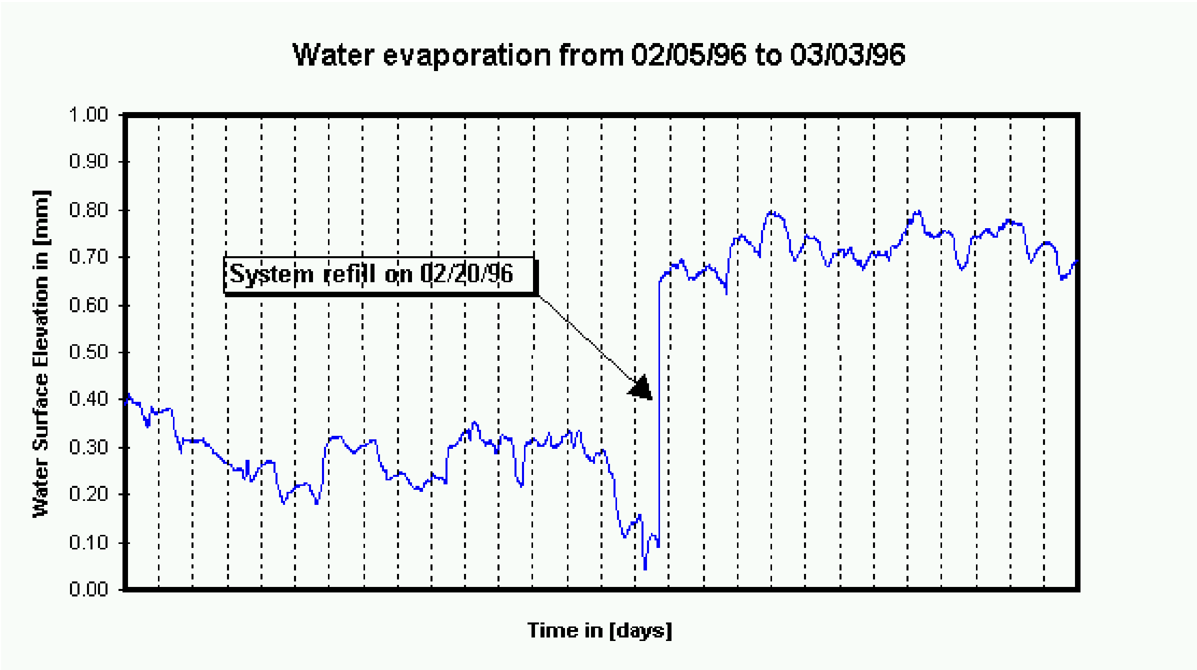

Fig. 11 February water evaporation

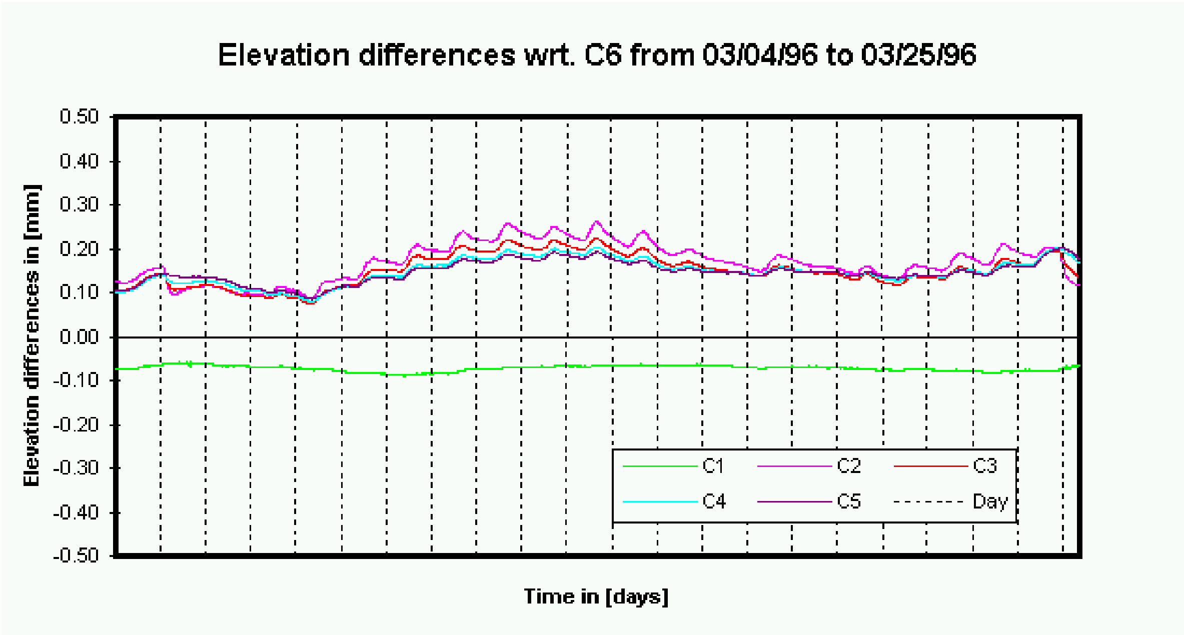

Fig. 12 March elevation differences

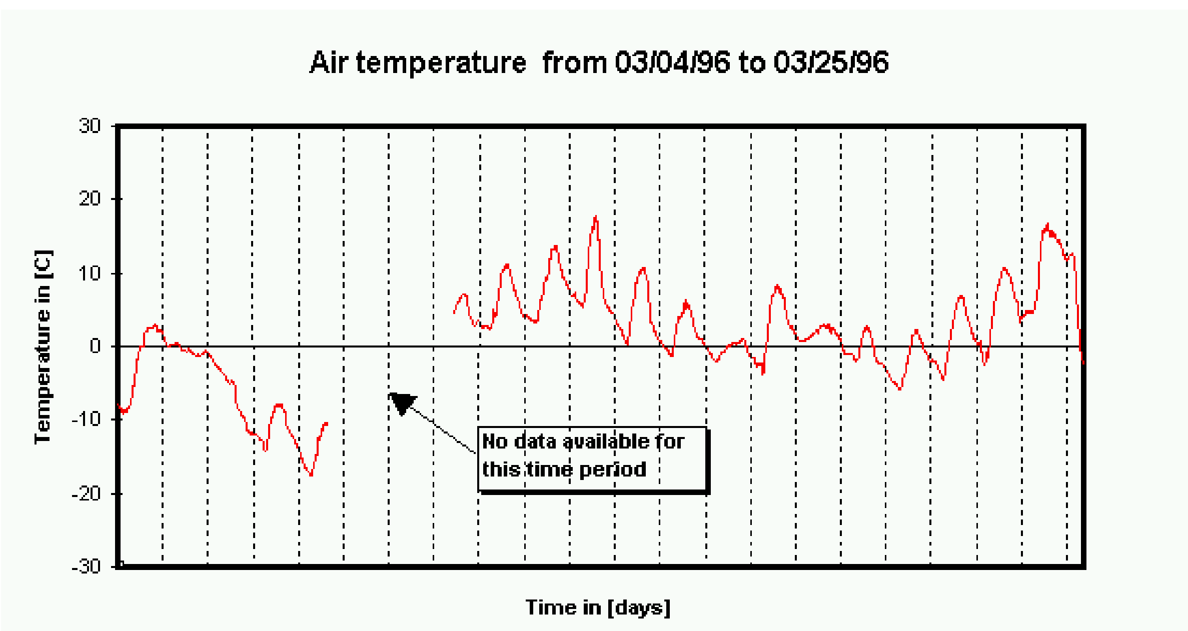

Fig. 13 March air temperature

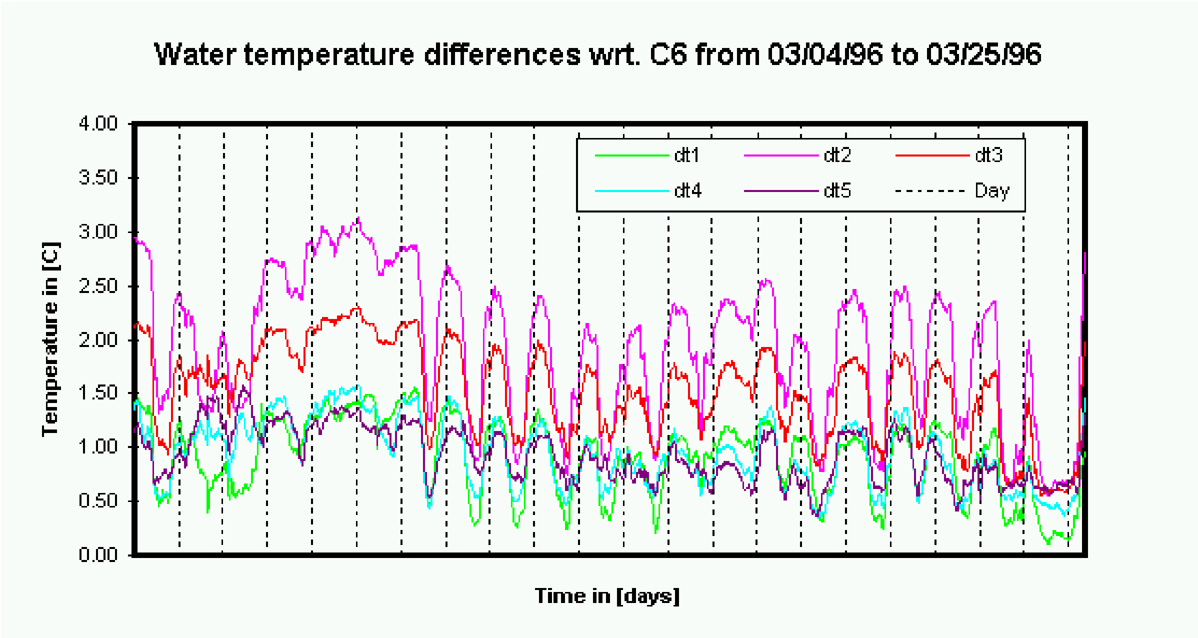

Fig. 14 March water temperature differences

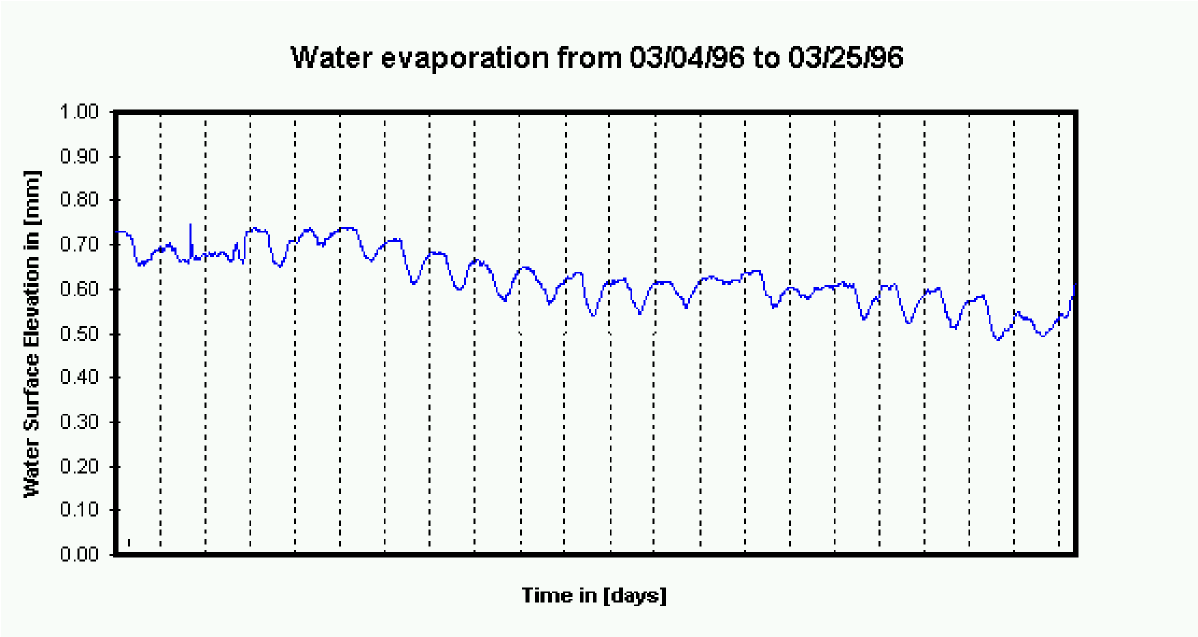

Fig. 15 March water evaporation

6. Summary

Figure 16 shows the correlation of the measured deformation and the recorded outside air temperature. A high correlation can be observed for sensors 2 to 5 mounted directly on the vehicle tunnel overpass. Sensor 1, used to provide redundancy for the reference sensor 6, does not show any correlation with temperature changes.

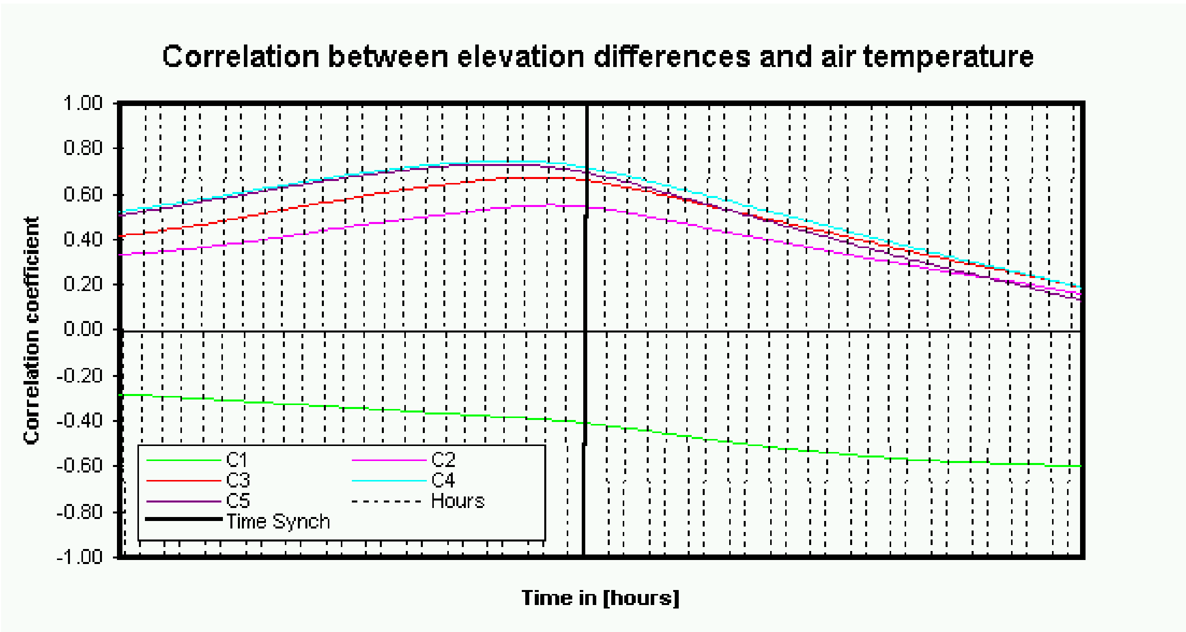

Fig. 16 Correlation coefficients

In addition one can see that sensor 2 has the smallest correlation coefficient and time lag between the onset of a temperature change to the onset of the deformation due to the temperature fluctuation. The correlation increases from sensor 3 to 4 and 5. At the same time the time lag increases. Table 2 lists the largest correlation coefficient and the time lag with respect to the time when the sensor readings and the temperature recordings were synchronous. It also shows the maximum and minimum recorded elevation for each sensor during the entire measurement period as well as the elevation differences and the distances between sensors.

Sensor	Corr. Coeff.	Time Lag	Maximum height	Minimum height	Δh	Dist. btw. Sensors
Units		[hours]	[mm]	[mm]	[mm]	(from-to) [m]
1	-0.28	N/A	0.055	-0.090	0.145	(1-2) 16.14
2	0.55	2	0.261	-0.406	0.667	(2-3) 4.23
3	0.67	2.5	0.225	-0.298	0.523	(3-4) 3.97
4	0.75	4	0.204	-0.203	0.407	(4-5) 3.96
5	0.73	4.5	0.202	-0.115	0.317	(5-6) 13.49

It is apparent that sensor 2 is closest to the outside wall of the storage ring enclosure and therefore experiences deformations due to temperature fluctuations first and with the largest displacements. The data recorded in March (Fig. 12 - 15) exhibit a daily temperature fluctuation of 10°C which results in a deformation of 25µm per day.

The reference sensor 1 shows only minor elevation changes over the entire recording period. The largest elevation difference between sensors 2 and 5 is on the order of ±0.3mm. This results in a tilt of ±0.018mrad of the overpass perpendicular to the user beamlines. Consequently, transverse displacements of about ±26µm at beam height can be expected at the vehicle tunnel overpass.

Finally, it should be mentioned that in preparation for the compensation of anticipated deformations resulting from large outside air temperature fluctuations, plastic hoses have been inserted in the concrete of the vehicle tunnel walls. This opens the possibility of stabilizing the area by pumping temperature-regulated water through these tubes. The data presented here may be useful in the decision making process for using that system.

7. References

[1] D. Martin, *"Applications of Hydrostatic Leveling in Civil Engineering,"* Proceedings of the Third International Workshop on Accelerator Alignment, CERN, Annecy, France, September 1993.

[2] D. Roux, *"Determination of the Accuracy of a Hydrostatic Level System Network,"* ESRF Working Report, September 1992.

[3] W. Busch, *"Eigenschaften stationärer hydrostatischer Präzisions- Höhenmeßsyteme für kontinuierliche Langzeitbeobachtungen untersucht an einem neuentwickelten Schlauchwaagensystem,"* Veröffentlichung des Geodätischen Instituts der RWTH Aachen Nr. 31, Dissertation, Aachen 1981.

[4] D. Roux, "*Alignment & Geodesy for the ESRF Project,"* Proceedings of the First International Workshop on Accelerator Alignment, Stanford Linear Accelerator Center, USA, July 1989.

[5] D. Martin, D. Roux, "*Real Time Altimetric Control by a Hydrostatic Leveling System,"* Proceedings of the Second International Workshop on Accelerator Alignment, DESY, Hamburg, Germany, September 1990.

[6] D. Roux, "*A Historical First on Accelerator Alignment,"* Proceedings of the Third International Workshop on Accelerator Alignment, CERN, Annecy, France, September 1993.

[7] W. Schwarz, *"Vermessungsverfahren im Machinen- und Anlagenbau,"* Vermessungswesen bei Konrad Wittwer Band 28, Stuttgart 1995.